OBSERVATION OF ELECTROKINETIC INSTABILITY IN A NEW DOUBLE CROSS-SHAPED MICROCHANNEL

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In this paper, numerical and experimental studies are performed to achieve a variety of hybrid types with electrokinetic instability (EKI) effects and to use them in different conductive applications of cross-shaped microchannels. First, this study considers two different types of electrolytes, namely the two electrolytes with the conductivity ratio between 1 and 10, and when the applied DC electric field strength is below the critical value, there will be a hierarchical flow conditions are formed. EKI phenomena are described as coming from the axial velocity and the flow pressure gradient, respectively. In fact, the nature of the electrokinetic instability depends on the relative direction of the conductivity gradient within the microchannel. In addition, a new designed double cross-shaped microchannel structure has also been fabricated and observed operating EKI phenomena. From the experiment, it also can be found that the distance of the upstream length has a profound impact on the mixing of disturbances downstream of the pipeline.

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1. Introduction

Over the past 20 years, many integrated electric micro-devices have developed a variety of functions, including sample preparation, mixing, separation, and more. This device is a key component of a so-called micro-analysis system that integrates multiple chemical analyzes in a single microchip. [1-2] In the field of microfluidics, the most common procedure is the use of biochemical wafers with a high conductivity gradient. The fluid is driven at a sufficient intensity by the external electric field to cause an unstable flow of the elevator, which is commonly referred to as EKI and can be considered as a special form of electro-hydro dynamic instability. [3-4]

Recently, microfluidic chips have been applied to various medical fields because of their advantages such as short separation time, small sample injection volume, high sensitivity, and easy operation of instruments. Biochips are the most popular one of them. The microfluidic chip usually using glass as a substrate has good light transmittance, bio-compatibility, and its process method is simple and inexpensive. It is quite helpful for us to develop a microfluidic chip with a specific detection function. [5-6]

During experimental process, sodium glass was used as a substrate to design and fabricate a group of microfluidic biochips. A series of tests were performed on the same or different samples using a voltage-driven method, and then various operating modes were found through experimental methods. In a recent study, the effluent effects and integrated valveless switching using EKI have been used for improved microfluidic channel mixing. [7-8] Also used electric field intensity disturbances to stir up EKIs to improve microfluidic mixing of T-type microchannels. Compared to passive and active research, this EKI-based micro-pipe design has a simpler manufacturing process and a basic voltage control.

In this study, a variety of electrolytes with a conductivity of 1 to 10 were used and the EKI formed by direct current fields was used to drive mixing. As the electric field strength increases, different EKI phenomena are also excited. The influence of the direction of the conductive

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gradient formed in the microchannel and the EKI phenomenon formed by the DC field will be discussed. These phenomena also explain the relationship between the respective axial velocity and the pressure gradient. [9] Next, a double cross microchannel structure has also been fabricated and observed. Through the theoretical analysis and verification of the actual work, a more in-depth understanding of the use of voltage-driven micro-channel fluid behavior, in the hope that in the future research can develop various types of microfluidic chip module.

2. Experimental

In experiment, a dioxide etching solution BOE was used to etch the glass. First, we pour the dioxide etching solution BOE into a container made of teflon, and the etching rate of the dioxide etching solution BOE is 1um/min, and the final etching depth of wafers is 20um. The prepared wafers were then used with a wafer drilling machine, and the holes to be drilled on the wafer were selected by suitable drill bit holes to be drilled. The drilled wafer is combined with another complete wafer, and a small amount of DI water is added to it to make sure that the gap is tighter. Then, it is placed in a high-temperature crucible and the temperature is set at room temperature 24°C within 3 hours to 690°C and maintain temperature at 690°C for 10 minutes. Finally, set the temperature to cool down from 690°C to room temperature 24°C for 5 hours. After this step, the selenium glass is tightly bound together.

In the experimental measurement, a mercury lamp is used as a light source, and the higher the concentration of the fluorescent agent is, the brighter the fluid is under the irradiation of the mercury lamp. If the fluid does not contain the fluorescent dye, there will not be any brightness, so it is convenient to use the naked eye to observe the flow of liquid and the disturbance of the mixed liquid. At the same time, the CCD image capturing system manufactured by Sony Corporation can be used to connect to a computer for viewing, and the microfluidic flow on a microfluidic wafer can also be recorded and observe changes. The entire experimental procedure flow is shown in Fig. 1.

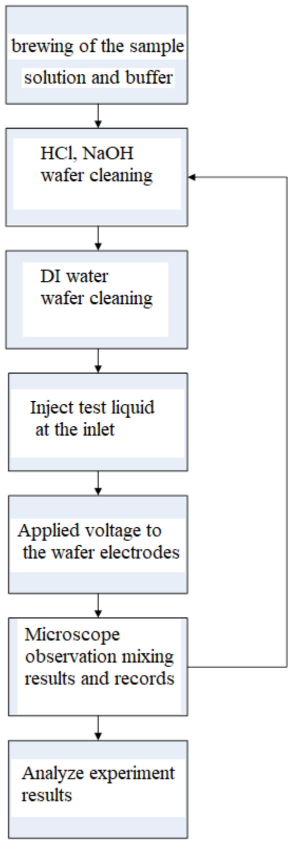


Fig.1. Schematic illustration of experimental procedure flow chart.

3. Results and discussion

Fig. 2 shows the cross-shaped microchannel geometry for numerical analyses. The inlet and outlet pipes have an inner diameter of 60μm, inlet 1 and inlet 2 and inlet 3 to the junction of 350μm, and the inlet-to-outlet piping is 1350um. [10] Fig. 3 illustrates the distribution of critical values in the two injection modes 1:M:1 and M:1:M. The injection mode is defined as the conductivity of the fluid introduced from the upper, lower, and lower inlets, respectively. M is a variable conductivity value with a size between 1 and 10. In the case of low conductivity, the critical value of the 1:M:1 mode is greater than the M:1:M mode. Then, when the M value exceeds 7, the critical value of M:1:M mode is greater than 1:M:1 mode. However, the gap between the critical values caused by the electric field strength is very small. Three different conductivity ratios of 3.5, 2.25 and 1 were injected into the cross-shaped pipe. First, the highest conductivity and lowest conductivity fluids are injected into the left and lower inlets, respectively, while the medium conductivity fluid is injected into the upper inlet. Under this injection configuration, delamination can still be clearly seen when the DC electric field intensity does not exceed 400 V/cm. Fig. 4 shows the phenomenon of fluid conduction under three conditions at an electric field of 778V/cm and time t=2 seconds. These formed vortex flows show an asymmetrical alignment phenomenon. This result shown in Fig.4 (a) is mainly due to the lower conductivity being lower than the upper conductivity rate. In the second case, the highest and lowest conductivity fluids are injected from the top and left duct inlets respectively; while the medium conductivity fluid is injected from below. Fig.4 (b) shows the three fluid conduction phenomena in the second case at an electric field of 778 V/cm at time t = 2 seconds. It can be seen from the observation that as time passes, the wavy flow will advance in the downstream direction while the wave height gradually becomes larger.

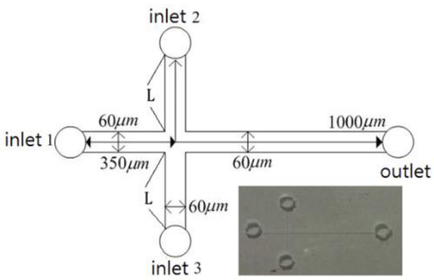


Fig. 2. Single cross-shaped microchannel structure with geometry, inlet and outlet positions.

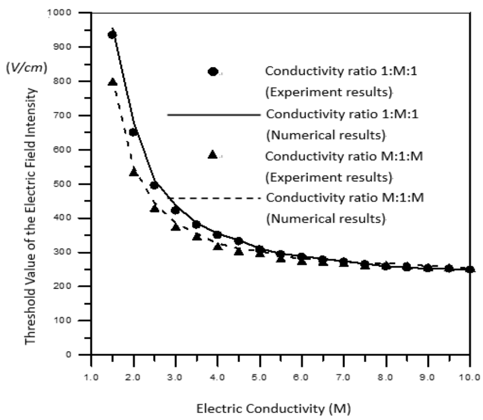
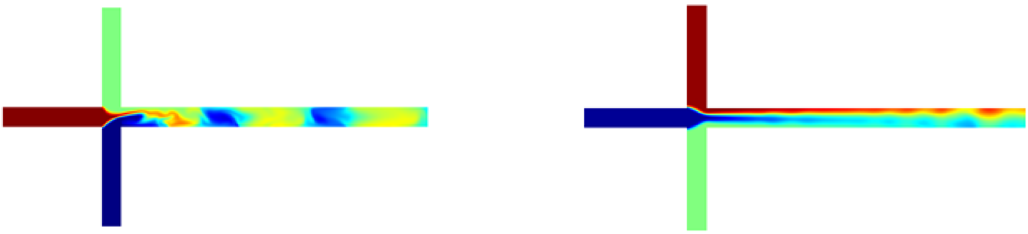


Fig. 3. Threshold electric field intensity distribution for different injection modes vs. different conductivity (M) ratios.



a) b)

Fig. 4. The flow distribution of the beam with different injection modes at a DC electric field strength of 778 V/cm at t = 2 sec (Note: blue indicates low conductivity solution, green indicates medium conductivity solution, red indicates high conductivity solution) under (a) 2.5:3.5:1 injection mode (b) 3.5:1:2.5 injection mode.

In addition, we also conducted experiments on double cross-shaped microfluidics. The disturbance of the electric instability of the double cross-shaped microfluidic tube structure is observed. In the experiment, we use a 3.5:1 electrolyte solution, which will be injected separately. At the entrance, the inlet 1, 4, and 5 are injected with a concentration ratio of 3.5, and inlets 2 and 3 are injected with a concentration ratio of 1. Double cross-shaped microchannel structure, experimental geometry and inlet/outlet positions are shown in Fig. 5. In the experiment, the interface will form a delamination phenomenon. During the measurement, the applied DC voltage is added to the entrance of the mixing pipe, and the downstream outlet of the mixing pipe is considered as the ground. When the electrical field is 405V/cm, the d length of the inlet 1 is greater than 175um. There is no disturbance in the observation, but there will still have five layers of interfaces revealed in the mixing pipeline as shown in Fig. 6 (a). At this moment, d length less than 175um (d=170um), a slight disturbance phenomenon is still not obvious as shown in Fig. 6 (b). If the electrical field up to 856V/cm and d still greater than 175um at entrance length d, no disturbance occurs, and there will still be a 5-layer interface in the mixing pipeline. Finally, while the electric field is 856V/cm and d length is less than 175 um (d=170um), the perturbation phenomenon finally appears and is very obvious as shown in Fig.6(c). The results show that when the length of d at the inlet of the pipeline is less than 175um and the strength of the applied electric field reaches a certain boundary, a wave with unstable perturbation will be formed at the inlet end of the mixing pipeline, and the fluid will be mixed and moved downstream. When d is less than 175um (take d=170um) and the input electric field 856V/cm and 405V/cm are input respectively, the experimentally measured mixing efficiencies are shown in Fig. 7. It can be seen from the figure that in this case, the critical electric field strength is about the center value of 405V/cm.

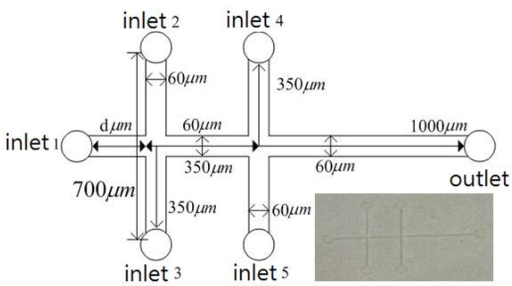
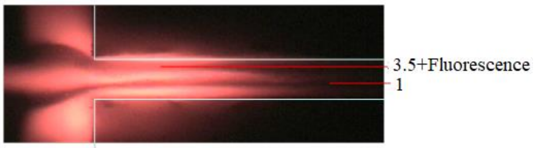
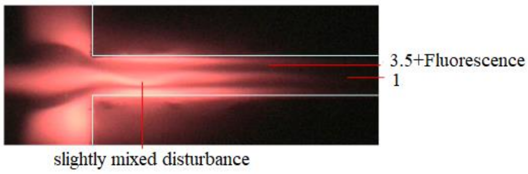


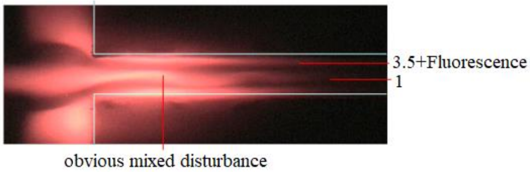
Fig. 5. Double cross-shaped microchannel structure with geometry, inlet and outlet positions, where d is a variable parameter.



(a)



(b)



(c)

Fig. 6. Fluorescent images of three fluid streams along a in a double cross-shaped mixing channel (a) d>175um, no disturbance, only layered phenomenon (b) d = 170um, E =405V/cm, slight mixing disturbance (c) d = 170um, E = 856 V/cm, obvious mixing disturbance.

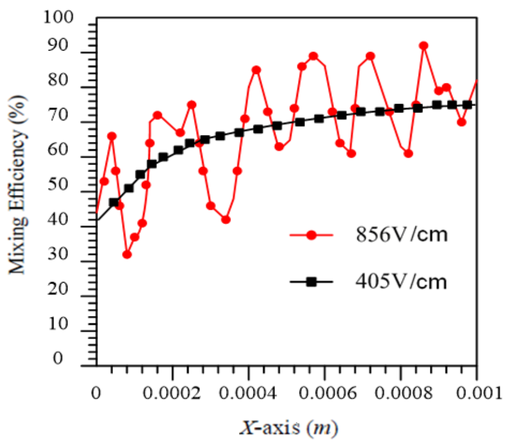


Fig. 7. In a double cross-shaped microchannel, the relationship between the mixing efficiency and the downstream distance of the X axis at d = 170 μm and the input electric field 856 V/cm and 405 V/cm as parameters, respectively.

3. Conclusion

In this study, numerical simulations and experiments were conducted to study the effects of electrokinetic instability effects, and cross-shaped microchannels were injected using external DC electric fields under different ion concentration flows. Two series of forms were explored in which two electrolyte solutions and three electrolyte solutions with a conductivity between 1 and 10 were studied. In general, the injection pattern shows that EKI electrokinetic instability causes a mixing effect in the microchannel. When the fluid is injected, the highest conductivity solution is in the middle of the three streams, and the conduction gradients of the central stream and the two outer streams are opposite to each other. In addition, a new double cross-shaped microchannel structure is fabricated and investigated. From experiment, it is found that the upstream distance d plays an important role on the downstream mixing effect. Based on the numerical and experimental results of the cross-shaped microchanels, it can enhance our understanding the physics of bio-microchip in general.

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